SIRTF – An Overview

Michael W. Werner*
Jet Propulsion Laboratory, California Institute of Technology

ABSTRACT

This paper reports on the status of SIRTF – the Space Infrared Telescope Facility. SIRTF will be a cryogenically-cooled space telescope instrumented with large-format, state of the art infrared detector arrays. SIRTF will complete NASA's family of Great Observatories and also serve as a cornerstone of the Origins program. SIRTF will be launched in 2001, carrying a complement of imaging and spectroscopic instrumentation, for a mission ~5yr in duration. SIRF will be placed in an earth-trailing heliocentric orbit; the very favorable thermal environment of this orbit has enabled a novel warm-launch architecture for the cryogenic system. More than 75% of the observing time on SIRTF will be available to the general scientific community. The community involvement in SIRTF began in June of 2000 with the formal release of the call for Legacy Science proposals.

Keywords: SIRTF, infrared astronomy, infrared detectors, cryogenics

1. INTRODUCTION TO SIRTF

The combination of the intrinsic sensitivity of a cryogenic space observatory with the imaging and spectroscopic power of high-performance, large format infrared arrays is extremely powerful scientifically. This combination led to SIRTF's designation in 1991 by the National Academy of Sciences in the 1991 Bahcall Report as the highest priority major new space mission for US astronomy in the 1990's. The system design and the related detector, cryogenic, and optical technology have evolved steadily since then, and the construction of SIRTF began in mid-1998, with launch scheduled for December, 2001. Consistent with this schedule, the SIRTF team was completed with the selection in 1996 of Ball Aerospace to provide the cryogenic and optical systems, and Lockheed-Martin to build the spacecraft and to carry out system integration and test. Project management, system engineering, flight operations, and science oversight are the responsibility of the Jet Propulsion Laboratory. SIRTF will carry three focal plane instruments: Dr. G. Rieke of the University of Arizona and Dr. J. Houck of Cornell University are the Principal Investigators for MIPS and IRS, respectively. These two instruments are being built by Ball Aerospace. Dr. G. Fazio of the Smithsonian Astrophysical Observatory is the Principal Investigator for IRAC, which is being built at the Goddard Space Flight Center. Data from SIRTF will be processed and disseminated to the scientific community through the SIRTF Science Center (SSC), located on the Caltech campus. Dr. T.Soifer is the Director of the SSC, and Dr. G.Helou the Deputy Director. All interactions of the scientific community with SIRTF - from proposal preparation through accessing the SIRTF data archive, will be through the SSC.

Up-to-date information on the status of SIRTF can be found on the SSC Web Site: http://sirtf.caltech.edu/.

2. THE SIRTF MISSION

SIRTF will be launched by a Delta rocket into an earth-trailing heliocentric orbit. The telescope will be launched warm and cooled when in orbit, while the three focal plane instruments will be cooled by liquid helium at launch and throughout the mission. This new system architecture permits the launch of SIRTF's 85-cm telescope in a lightweight configuration which brings SIRTF within the launch capabilities of the Delta (the launch mass of SIRTF is expected to be subsantially less than the limit of 905kg set by the launch vehicle). The cryogenic system is based on a 1.4K liquid helium bath which cools the instruments, while the helium vapor produced by the dissipated instrument power will be used to cool the telescope to its operating temperature of <5.5K. This vapor cooling supplements the on-orbit radiative cooling, allowing SIRTF to achieve a cryogenic lifetime greater than 2.5 years with only 350 liters of liquid helium. Current models predict a lifetime of order 5 years. SIRTF will have a pointing accuracy of <2" and stability of a fraction of an arcsec for long periods. Precision offsets will allow targets to be placed on spectrograph slits with sub-arcsecond accuracy. The principal features of the SIRTF mission are summarized in Table 1.

*Correspondence: Email: mwerner@sirtfweb.jpl.nasa.gov

In addition to providing a benign, stable thermal environment the heliocentric orbit has great operational benefits. About one-third of the sky is visible - continuously - at any one time, as SIRTF can routinely point as close as 80 degrees to the sun and as far as 120 degrees off the sun. Targets within this angular range can be observed for a minimum of 40 days consecutively. Of course, in the heliocentric orbit there are no eclipses and no need for Earth avoidance maneuvers. The only complications are in the telecommunications arena, as in this orbit, SIRTF drifts slowly away from the Earth, reaching a distance of ~0.2au in 2.5 yr. Downlink is accomplished using a high gain antenna fixed on the bottom of the spacecraft; spacecraft body pointing is used twice per day to point the antenna at the Earth so that stored data can be sent down via the Deep Space Network.

TABLE 1: SIRTF MISSION CHARACTERISTICS

Aperture	85 cm
Diffraction Limit	6.5um
Image Size	~1.5 arcsec@6.5um
Telescope Temperature	<5.5K
Wavelength Range:	
Imaging and Mapping	3.5-160um
Spectroscopy	5-40um
Spectral Energy Distribution	50-100um
Pointing:	
Accuracy	<2 arcsec (1sigma)
Stability	0.3 arcsec (1sigma)
Offset Accuracy	0.4 arcsec (1sigma)
Planetary Tracking Rate	up to 1.0 arcsec/s
Orbit	Heliocentric, 1au
Lifetime	2.5-to-5 years

3. SIRTF INSTRUMENT CHARACTERISTICS

Although the three SIRTF instruments have differing functional capabilities and scientific niches, there are important commonalities among them. Most notably, each makes extensive use of large-format infrared detector array technology which is now available to the scientific community. In addition, the instruments are simple with a minimum of moving parts. As a result, the SIRTF user is presented with a restricted set of only 7 operational modes, which simplifies and reduces the cost of operations. The top-level properties of the three instruments are summarized below; detailed descriptions are presented in the other papers in this SPIE conference and proceedings. An important characteristic of the instruments is their very low cryogenic power use, typically <5 mw is dissipated into the liquid helium. The scientific performance achievable with SIRTF's instruments under various conditions is tabulated in detail and updated periodically on the SIRTF Science Center webpage cited above. "Walking-around" numbers are provided in the paragraph below; for comparison, SIRTF can achieve flux levels one-to ten-thousand times fainter than did the IRAS all-sky survey, and ten- to one-hundred times fainter than will be achievable with large ground-based and airborne facilities during SIRTF's lifetime. Under most circumstances, SIRTF's detectors will allow SIRTF to achieve natural-background limited sensitivity; that is, the sensitivity will be limited only by the fundamental fluctuations in the faint infrared background of the space environment, not by the intrinsic noise of the detectors themselves.

3.1. MIPS – The Multiband Imaging Photometer for SIRTF

MIPS provides mapping and imaging at wavelengths of 24, 70, and 160um and low (~15) resolving power spectrophotometry from 50 to 100um. The principal imaging 32x32 pixel Ge:Ga array, also with a 5.3x5.3 arcmin field of view The 160um imaging uses a 2x20 pixel array of stressed Ge:Ga detectors, providing a total field of view of 0.5x5.3 arcmin. Typical imaging sensitivities (all sensitivities quoted here are 5-sigma in 500s) of these arrays are 250uJy, 1.5mJy, and 7.5 mJy, respectively. Further details about MIPS and its detectors are given in papers by Hesselroth et al (2000) and Rieke et al (2000).

3.2. IRS – The Infrared Spectrograph

IRS provides low and moderate resolution spectroscopy at wavelengths from 5 to 40um. The instrument consists of four separate modules. Two of these provide low resolution (R~60-120) spectroscopy and two provide moderate resolution spectroscopy with R~600. Each of the four modules contains a single 128x128 Si:As (IBC) or Si:Sb (IBC) array; at low resolution, a long slit (~1') permits imaging in the cross-dispersion direction, while in the two moderate resolution modules the array is used in a cross-dispersed echelle mode. The low resolution modules cover the wavelength ranges 5-15 and 15-40 with sensitivities 550uJy and 5mJy, respectively. The wavelength ranges of the moderate resolution modules are 10-20 and 20-37um, and each has a sensitivity of $4x10^{-18}$ w/m+2. Because the spectrograph slits are as small as a few arcsec in width, the IRS also incorporates a peak-up feature which allows autonomous acquisition of an infrared target and commands the precision offset required to place the target on the slit with subarcsecond precision. The IRS is discussed in detail by Houck (2000).

3.3. IRAC – The Infared Array Camera

IRAC provides wide-field imaging at four near infrared bands centered at 3.6, 4.5, 5.8, and 8um. A 256x256 pixel array is used in each band; InSb at 3.6 and 4.5 and Si:As (IBC) at 5.8 and 8um. A dichroic beamsplitter allows the 3.6 and 5.8um arrays to view the same 5x5 arcmin field of view; an adjacent 5x5 arcmin field is viewed simultaneously by the 4.5 and 8um arrays. The predicted sensitivities of the IRAC arrays are 5, 8, 35 and 35uJy, respectively, at 3.6, 4.5, 5.8, and 8um. The IRAC and its detector arrays are discussed in papers by Pipher et al (2000), Hora et al (2000), Jones-Selden et al (2000), and McMurray et al (2000).

4. THE SPACECRAFT, TELESCOPE, AND CRYOGENIC SYSTEMS

A comprehensive description of the SIRTF spacecraft, telescope, and cryogenic systems, and a discussion of how they accommodate the three instruments, is presented by Fanson et al (1998), while an updated report on the cryogenic/thermal system, including initial test results, is provided by Hopkins et al (2000). As system integration proceeds, the telescope, the cryostat, the instruments, and accompanying thermal shields are assembled together; the instruments are in a cold multiple instrument chamber within the cryostat and in close contact with the helium. This level of assembly will be achieved in the Fall of 2000. The lightweight, all-Beryllium telescope is mounted above the cryostat; as mentioned earlier, SIRTF is launched with the cryostat full of liquid helium, so that the instruments are cold, but the telescope itself is warm and cools down on orbit by a combination of radiative cooling and vapor cooling from the evaporating liquid helium. This cooldown requires about 50 days.

Following the integration and test of the cryostat/telescope/instrument assembly, this assembly will be mated to the spacecraft early in 2001. The spacecraft sits behind the cryostat/telescope/instrument assembly; a fixed solar panel shields the cryostat/telescope assembly and provides ~350W of electrical power needed for on-orbit operations. Among the unique features of the spacecraft are a reaction control system which uses high pressure nitrogen gas to unload the reaction wheels, as the magnetic torquing possible in low earth orbit is not an option in SIRTF's heliocentric orbit. The most challenging component of the spacecraft is the pointing and control system, because SIRTF has relatively stringent pointing requirements, and because the cold inner portions of the telescope and the cryogenic system are only weakly coupled mechanically to the spacecraft. The spacecraft is body-pointed using reaction wheels to an accuracy of better than 2 arcsec as determined by an externally mounted star tracker. The alignment of the spacecraft to the telescope is checked periodically by the use of a centroiding star sensor in the cryogenic focal plane and adjustments are made as necessary. A similar architecture was used for pointing the Infrared Space Observatory (ISO). It is estimated that the misalignments due to the changing thermal state of the system will be small compared to 2" in SIRTF's thermally stable and benign orbit. The stability of the line of sight is monitored and maintained by a set of gyroscopes mounted in close proximity to the star tracker. The spacecraft has no articulated components (both the solar panel and the high gain antenna are fixed).

Another important feature of the orbit is that the outer shell of the telescope will achieve a temperature ~40K by a combination of radiative cooling and careful control of the heat conducted and radiated through the observatory. At this temperature, the parasitic heat conducted into the telescope and the cryostat will be very small. Thus the principal heat load into the helium is the <5 mw dissipated by the instrument cold assemblies. It is the combination of this small power dissipation and the absence of appreciable parasitic loads which allows SIRTF to achieve its long lifetime with an initial helium capacity considerably less than that of previous missions such as IRAS, COBE, or ISO.

SIRTF's 85-cm diameter, all-Beryllium telescope has a mass of about 35kg. Both the primary mirror and the entire telescope have been repeatedly cycled to cryogenic temperatures in a cryogenic test facility at JPL (Pearson et al 2000). The cryogenic performance and the reproducibility of the telescope are excellent, and it appears that SIRTF will meet its requirement of diffraction-limited imaging at 6.5um across the entire ~30 arcmin diameter field of view. The telescope incorporates a focus mechanism which can adjust the axial position of the secondary mirror if needed following on-orbit cooldown.

5. SIRTF OPERATIONS

The operational features of SIRTF are described by Bicay et al (1998). Briefly, the operations are built around a small group of AOT's, or Astronomical Observing Templates, which for the present purposes are equivalent to the allowable observing modes of the payload and describe the way in which a scientist can use SIRTF. Corresponding to the seven observing modes there are seven AOT's: IRAC staring, IRS staring, IRS scanning, MIPS scanning, MIPS photometry/super-resolution, MIPS spectral energy distribution mode, and MIPS total power mode. Each of these exercises a different set of instrument and spacecraft capabilities, but together they encompass all ways in which SIRTF can be used for scientific observations.

On the uplink side, following the usual proposal peer review and time allocation process, an approved observation is submitted to the scheduling pool in the form of a completed AOT filled out by the observer. In routine operations, an observing timeline containing about one weeks' worth of AOT's will be uplinked to the spacecraft about once per week. The uplink can be carried out simultaneously with the downlink during one of the twice-daily data dumps referred to earlier.

The scheduled observations will be stored on the spacecraft and executed autonomously - there will be no real-time or "joystick mode" operations with SIRTF. Only one instrument will be powered on and taking data at a given time, and to simplify scheduling and minimize the impact of instrument changeovers, it is anticipated that the instruments will be scheduled serially in blocks of order 5 to 15 days.

The observing sequences will include routine calibration observations - scheduled by the SSC - as well as the uplinked science observations. The downlinked science and calibration data will be put through an automated analysis pipeline within 12 hrs of receipt on Earth. The output products from the pipeline will be a calibrated image for each individual exposure and browse-quality products - such as mosaics and spectra extracted from echellograms - which are indicative of the scientific content of an entire observation. The data will be archived by the SSC and the user notified of their availability electronically. It is expected that prior to undertaking scientific analysis of the data most observers will wish to improve upon the browse-quality products - and also to create additional data products of various sorts - through the use of standard astronomical data processing software or of a limited set of SIRTF-specific tools to be made available by the SSC.

The routine operational scenario described above will be largely automated following the original uplink of the observing sequence. However, the SIRTF operations system will also be capable of responding to Targets of Opportunity - with an approved observation being executed within 48 hrs of approval. It will also accommodate other special requirements, such as requests for unique calibrations and the need to update a solar-system target ephemeris shortly before an observation.

6. SIRTF SCIENCE AND SCIENTIFIC UTILIZATION

6.1. General scientific context

The sensitivities quoted above for SIRTF promise major advances in capability over previous and current facilities for infrared astronomy, from ground or space. This, together with the highly efficient imaging and spectroscopy which will be capable with SIRTF 's wide field, array-based instrumentation, endows SIRTF with a high degree of "discovery potential" for uncovering new phenomena in the Universe. This combines with the advances SIRTF can make towards the understanding of known astrophysical problems to make SIRTF a powerful bridge between NASA's Great Observatories program, represented by HST and the Chandra X-Ray Observatory , and the new generation of Origins missions, represented by NGST - Next Generation Space Telescope (see Werner 1998 for a discussion of SIRTF and NGST). SIRTF's potential contributions to the study of planetary science and extra-solar planetary systems have been reviewed recently by Cruikshank and Werner (1997), while Werner (1997) and Werner and Eisenhardt (1995) have discussed extragalactic investigations which could be carried out from SIRTF. The scientific and technical coupling of SIRTF to the other elements of NASA's Origins program is discussed by Bicay and Werner (1998). Finally, a comprehensive review of the science achievable with infrared surveys, with particular emphasis on the forthcoming role of SIRTF, is contained in a recently published conference proceedings (Bicay et al, 1999; see also Werner (1999)).

6.2. Community utilization of SIRTF

At least 75% of the observing time on SIRTF will be made available to the general scientific community through a peer-reviewed proposal process. (The remainder of the observing time will be divided between Guaranteed Time Observers and Director's Discretionary Time). Two separate types of community participation in SIRTF's observing programs are envisioned, Legacy Observations and General Observations. (Director's Discretionary Time, which amounts to 5% of the total, will also be accessible to the general community).

The objective of the Legacy Program is not only to do excellent science but also to develop data bases upon which SIRTF users can base follow-on proposals. This is an essential component to the scientific utilization of SIRTF, because of its short life time, high sensitivity, and substantial discovery potential. The Legacy Programs will be solicited from the general scientific community and the teams selected prior to launch so that the Legacy Observations can begin early in the mission; the solicitation is in progress at the present time, with proposals due in mid-September, 2000. Depending on the programs proposed and selected, as much as 50-70% of SIRTF's first year on orbit might be devoted to Legacy Science. Legacy Science projects will almost certainly include a number of surveys - both unbiased and targeted.

General Observations will constitute the remainder of the community utilization of SIRTF. GO selections will take place every nine to twelve months. The first solicitation will be prior to launch, and GO observations will be scheduled starting about nine months after launch. In addition, the SIRTF archive will be publicly accessible starting about six months after launch, and a funded archival research program will be supported during the mission.

To summarize, the major milestones for community utilization of SIRTF are scheduled as follows:

Call for Legacy Science Proposals - June 2000
Selection of Legacy Science Teams - November 2000
First Call for General Observations - October 2001
Launch of SIRTF - December 2001
Beginning of Scientific Observations (Legacy/GTO) - February 2002
Response Date for First General Observer Call - April 2002
Second Call for General Observations - November 2002

7. SUMMARY AND CONCLUSIONS

The launch of SIRTF in December 2001 will make a powerful new scientific tool available to the international scientific community. In many instances, SIRTF will work synergistically with other space- and ground-based facilities to enable the multi-spectral studies essential in attacking many key astrophysical questions. In other cases, SIRTF's ultra-sensitive infrared observations may define new arenas of astrophysical investigation. In addition to its invaluable scientific legacy, SIRTF is pointing the way for future missions by demonstrating key technologies in space: high performance, large detector arrays; a novel hybrid radiative-cryogenic cooling system; lightweight optics; and operation of an astrophysical observatory outside of the familiar low Earth orbit environment. Finally, SIRTF has implemented a number of important management innovations. These include engaging the general scientific community in its major initial science thrusts through the Legacy Science Program and novel and highly successful teaming arrangements which have led to unprecedented cooperation among the teams responsible for providing the key elements of the SIRTF system.

ACKNOWLEDGMENTS

The work described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under an agreement with the National Aeronautics and Space Administration.

REFERENCES

1. Bicay, M.D., Werner, M.W., Simmons, L.L. and Latter, W.B. 1998, *Proc. SPIE*, 3356, 653.
2. Bicay, M.D., and Werner, M.W. 1998,in *Origins*, ed. C. E. Woodward, J. M. Shull, and H. A. Thronson, Jr., ASP Conference Series, 141, in press.
3. Bicay. M.D., Beichman, C.A., Cutri, R.M., and Madore, B.F. eds. 1999, *Astrophysics with Infrared Surveys: A Prelude to SIRTF,* ASP Conference Series 177.
4. Cruikshank, D.P., and Werner, M.W. 1997, in *Planets Beyond the Solar System and the Next Generation of Space Missions*, ed. D. Soderbloom, ASP Conference Series 119, 223.
5. Fanson, J., Fazio, G., Houck, J., Kelly, T., Rieke, G., Tenerelli, D., and Whitten, M. 1998, *Proc. SPIE*, 3356, 478.
6. Hesselroth, T., et al. 2000, *Proc.SPIE*, paper 4131-05.
7. Hopkins, R.A., et al. 2000, *Proc. SPIE*, paper 4131-04.
8. Hora, J.L., et al. 2000, *Proc. SPIE*, paper 4131-03.
9. Houck, J.R. 2000, *Proc. SPIE*, paper 4131-09.
10. Jones-Selden, F.L., et al. 2000, *Proc. SPIE*, paper 4131-07.
11. McMurray, R.E., Jr., et al. 2000, *Proc. SPIE*, paper 4131-08.
12. Pipher, J.L., et al. 2000, *Proc. SPIE*, paper 4131-02.
13. Rieke, G.H., et al. 2000, *Proc. SPIE*, paper 4131-06.
14. Werner, M.W., and Eisenhardt, P.R.M. 1995, in *Airborne Astronomy Symposium on the Galactic Ecosystem: From Gas to Stars to Dust*, ed. M.R.Haas, J.A.Davidson, and E.F.Erickson, ASP Conference Series 73, 169.
15. Werner, M.W. 1997, in *Extragalactic Astronomy in the Infrared*, ed. G.A.Mamon, T.X.Thuan, J.Tran Thanh Van, Paris: Editions Frontiers, 571.
16. Werner, M.W. 1998, in *Science with the NGST*, ASP Conference Series 133, 53.
17. Werner, M.W. 1999, in *Astrophysics with Infrared Surveys: A Prelude to SIRTF*, ASP Conference Series 177, 451.